Fermilab

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To: Nelson Chester, Main Injector Project Manager

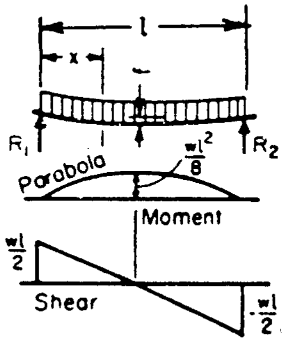
From: Jim Kerby, Technical Support / Engineering J. Kerby

Subject: MI Beam Tube Analysis

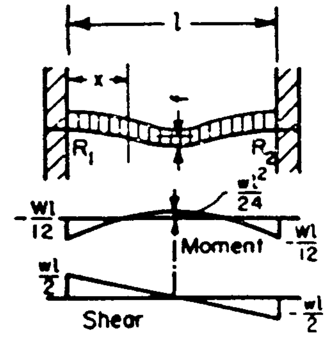
An analysis of the proposed beam tube for use in the Main Injector dipole magnets has been completed. The model considers a stainless steel tube, of varying wall thickness and width. The purpose was to minimize the wall thickness in the final beam tube design for the expected pressure loads.

The ANSYS model is a (by symmetry) quarter model, as shown in Figure 1. The outside dimensions are from FNAL drawing 5520-MC-274314 (revision none). The model is linear and elastic, with an assumed material modulus of 28.3×10^6 psi. STIF42 elements are used throughout. The width of the model was changed by moving the side wall out the desired distance, the wall thickness varied by keeping the outer dimension constant and moving the inner dimension towards the beam tube center. The load was an external pressure, of 15 psi, everywhere. This is the maximum possible load since this is due to an internal vacuum, not an external pressure source.

To bound the problem, we can look to two analytic solutions to the deflection of a transversely loaded beam. One, where the ends are freely supported, and the other where the ends are supported and restrained. Schematics and equations for these two cases are shown below (from Mark's Handbook, Ninth Ed., p 5-24).



$$f = \frac{W}{EI}\frac{5l^3}{384}\ \text{(max)}$$



$$f = \frac{W}{EI}\frac{l^3}{384}\ \text{(max)}$$

For the case of the beam tube, the equations reduce to:

$$\delta_{free} = \frac{5 \; P \, L^4}{32 \, E \, t^3} \qquad\qquad \delta_{fixed} = \frac{P \, L^4}{32 \, E \, t^3}$$

The actual beam tube deflection should fall between these two, since the end of the long side is prevented from rotating freely by the stiffness of the side wall.

A check of the ANSYS mesh against the analytic solution (using a simple beam) gives deflections of 0.0477" (ANSYS) and 0.0486" (analytic), a 1.8% difference. With some confidence in the model, the actual design was input, with the results tabulated below. Figures 2 and 3 present the deformation and stresses typically induced by the loading.

Table 1. Calculated Deflections

		Beam Calculation		ANSYS	
L	t	δ_{free}	δ_{fixed}	δ_{max}	σ_{vm}
4.625"	0.049"	0.322"	0.064"	0.106"	44.9 ksi
	0.065	0.138	0.028	0.045	25.4
6.000	0.049	0.912	0.183	0.296	82.5
	0.065	0.391	0.078	0.125	47.3
	0.084	0.181	0.036	0.057	28.7
	0.091	0.142	0.029	0.045	24.6
8.000	0.049	2.883	0.577	0.886	161.7
	0.065	1.235	0.247	0.377	92.7
	0.132	0.148	0.030	0.043	23.5

The ANSYS results suggest that the supported end of the beam tube acts more like a restrained than a free end, as could be expected from the rather short moment arm provided by the side wall of the tube.

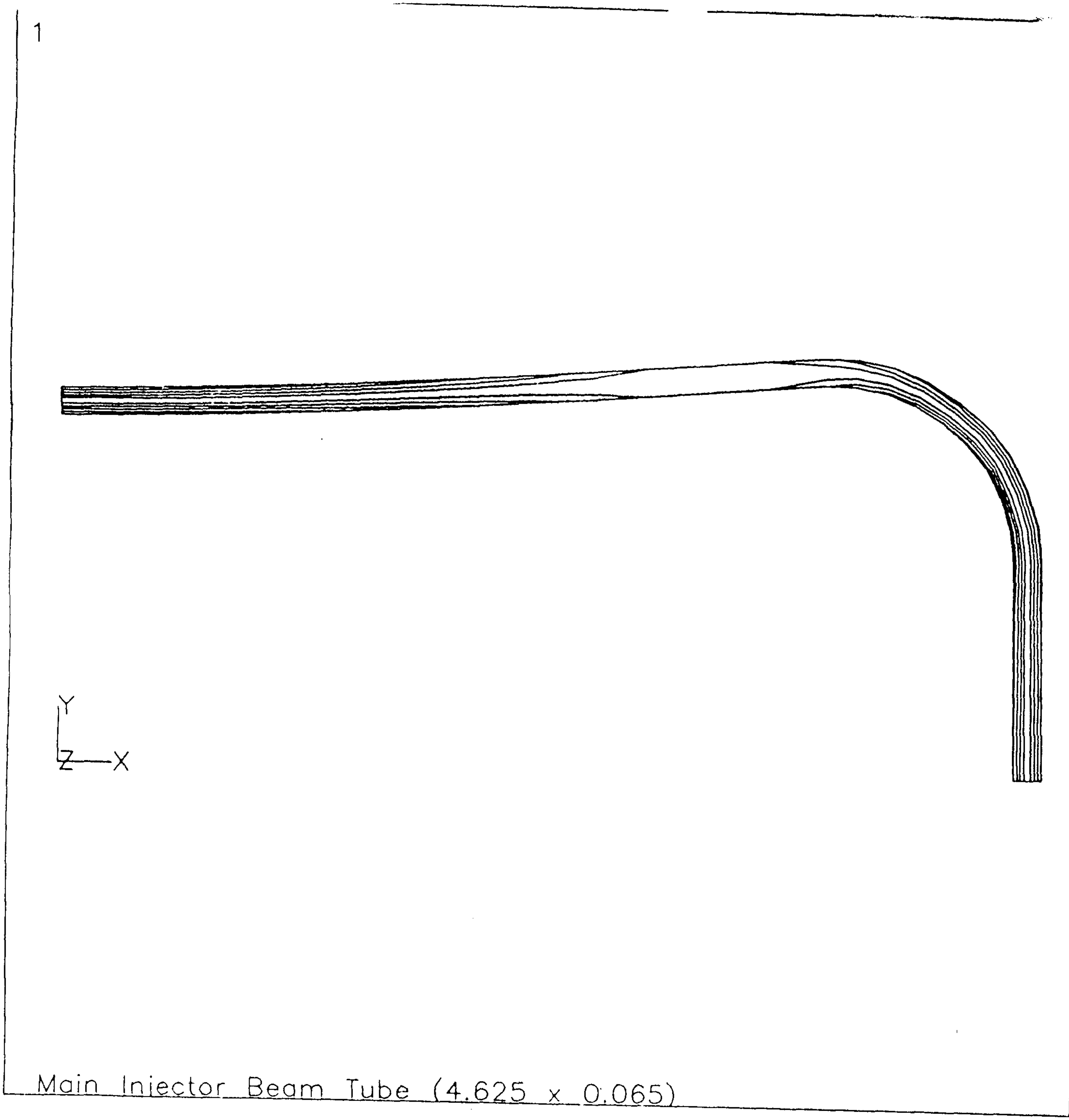
The results, both deflection and stresses, scale as expected for the differing sizes. Other variations on the geometry can be derived from these calculation by the following ratios:

deflection: $\delta_{max} \; \alpha \; (P, L^4, t^{-3})$

stress: $\sigma_{vm} \; \alpha \; (P, L^2, t^{-2})$

The stresses peak at the symmetry lines, due to the bending of the walls in these regions. If a welded seam is deemed necessary, the weld should be located on the long side, approximately 1.0" to 1.5" in from the side wall. This location minimizes the stresses which the weld would be subjected to.

For a 6 inch wide tube, I would suggest a 0.091" wall thickness.



ANSYS 4.4
SEP 11 1990
14:44:41
PLOT NO. 3
POST1 STRESS
STEP=1
ITER=1
SIGE (AVG)
DMX =0.045022
SMN =230.223
SMX =25411

ZV =1
DIST=1.272
XF =1.156
YF =0.5
EDGE

Figure 3. Von Mises Stresses in Beam Tube (contours are 5000psi apart, maximum stress 25411 psi)

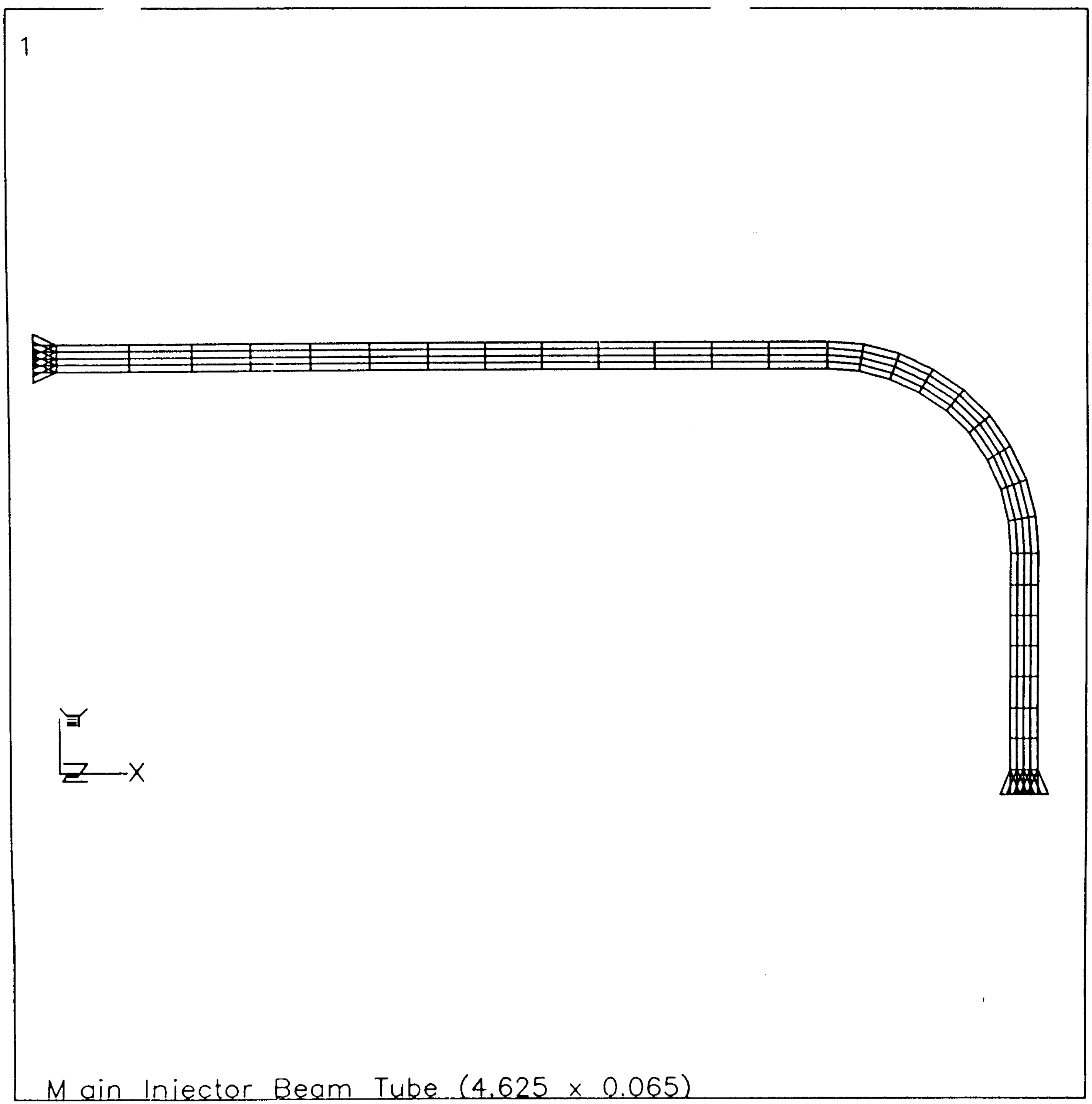


Figure 1. ANSYS Model
(including symmetry
boundary conditions)

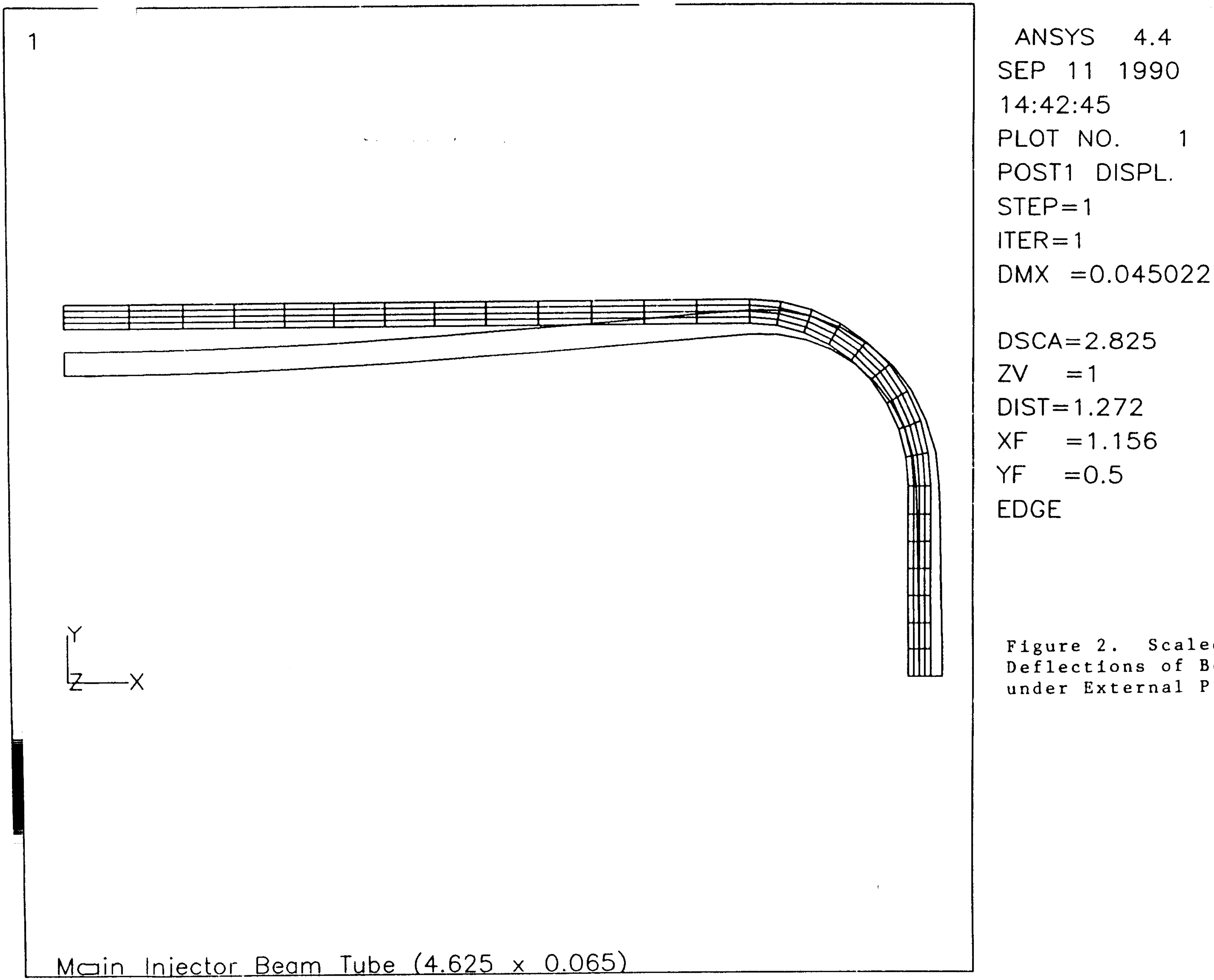


Figure 2. Scaled Deflections of Beam Tube under External Pressure

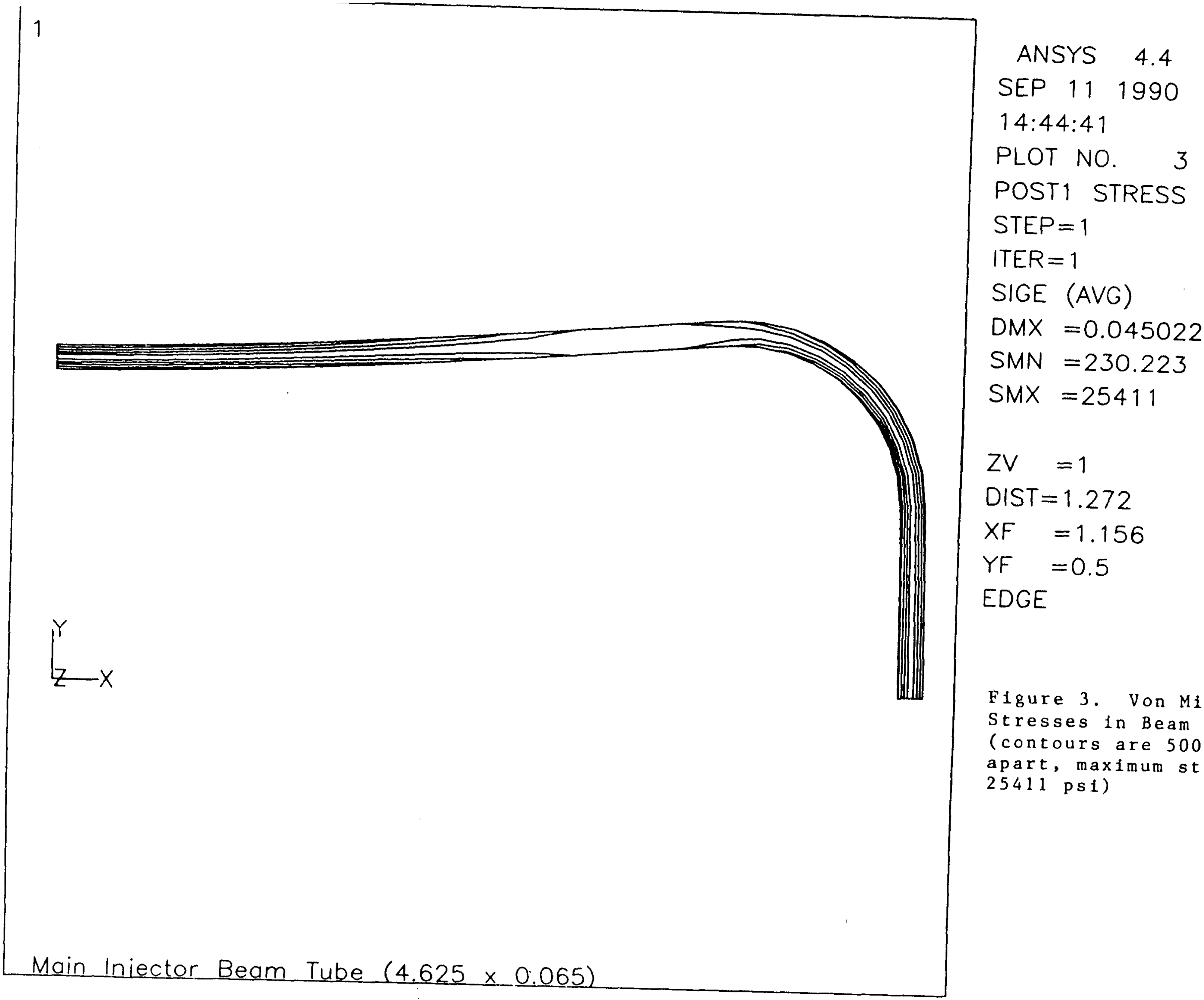


Figure 3. Von Mises Stresses in Beam Tube (contours are 5000psi apart, maximum stress 25411 psi)

From: ALMOND::HARDING   "Dave Harding, X4725, X2971" 7-NOV-1990 10:16:01.92
To: @MIMP
CC:
Subj: Dipole and beampipe notes from 2 Nov 90 MIMP

Main Injector Magnet Physics Meeting
2 November 1990
David Harding

1) Bruce Brown discussed progress in measuring the first Main Injector Dipole prototype, IDM001. Measurements and calibrations have been done using an NMR probe and two Hall probes. Difficulties remain with the power supply system, which has an unacceptable ripple.

To find the zero-field offset of the Hall probe, Bruce inserted it into a mu-metal shield and made several measurements at each of several probe orientations. With the correction for offset included, the probe up and probe down readings of the remnant field agreed to within the scatter of the points for any one measurement condition. The remnant field is about 12 Gauss. The sigma of the measurements is 1.3 Gauss.

The field saturation and the hysteresis can be seen in both the NMR and Hall probe measurements. Over the region where the NMR system works the two system agree very well. At the design operating current the NMR measures the field to be about 300 Gauss higher than the design field. Further work needs to be done verifying the calibration of the power supplky current readback. We need to check that the field is correct in the unsaturated region to be sure that the over-achievement is due to the steel properties and not to an incorrect gap height.

The B vs I measurements will be repeated and work on the power supplies will be worked on. Next, integral B.dl vs I will be measured with the stretched wire system. Integral B.dl vs X may be possible, but power supply noise limits the usefulness of that measurement unless a reference probe is used. Probably the next measurement after that will be harmonics with a rotating coil completely inside the magnet (no end field) to learn about the lamination shape. Perhaps in December a curved flatcoil probe will be available for further measurements of the lamination shape. The probe will cover most of the length of the magnet, but not the end field, at several heights. Also in December, we should have a scan of B vs x with the NMR and Hall systems.

2) Fred Mills offered to make some calculations on the effects of the bus work on the end fields and the effect of the end fields on the particles. Jim Dowd will follow up on getting design drafters to prepare drawings of the bus work on the magnet as installed on the test stand in IB1.

3) Jim Kerby presented his calculations on beam-pipe strengths. The main conclusion is that for a stainless steel beampipe of height 2 inches and width 4.625 inches, a wall thickness of 0.065 inches is sufficient. This is the dimension that Francois has been using in his calculations. This does not meet ASME standards for a pressure vessel, but that can hardly be considered necessary. It is less than a factor of two away from the yield point.

The beam pipe crosssection considered for the majority of the calculations was basically rectangular with corners of radius 0.5 inch. The peak stress comes at the horizontal mid-plane.

The peak stress is proportional to the pressure (assumed constant at air pressure vs vacuum), proportional to the square of the beampipe width, and inversely proportional to the square of the wall thickness. Thus increasing the width to 4.75 inches only increses the peak stress by 5%, but increasing the width to 5.25 inches increases the peak stress by 29%, to very close to the yield point. The next thicker standard wall, 0.075 inch, would be a good match to a width of 5.25 inches.

The deflection of the center is proportional to the pressure, proportinal to the fourth power of the beam pipe width, and inversely proportional to the cube of the wall thickness. The deflection of the center of the 4.625-inch beampipe due to the vacuum load is 1/32 inch. Pre-stressing the beampipe could compensate for the deflection, but would not relieve the level of the peak stress at the sides.

There was a wide-ranging discussion of beam pipe options. The conclusion was that given the radius of curvature needed, it might be fairly easy to buy straight beam pipes and wedge them into the magnet with the correct curvature. The thinner wall definitely has an advantage for the eddy currents. The higher resistance stainless steel would reduce the eddy currents to 2/3 the level of the standard material. The question of using titanium for beam pipes was raised, but no one present knew whether it had ever been seriously considered.

Eddy current calculations are available in Francois's MI Note. Under nominal conitions the peak sextupole field generated is about five units.